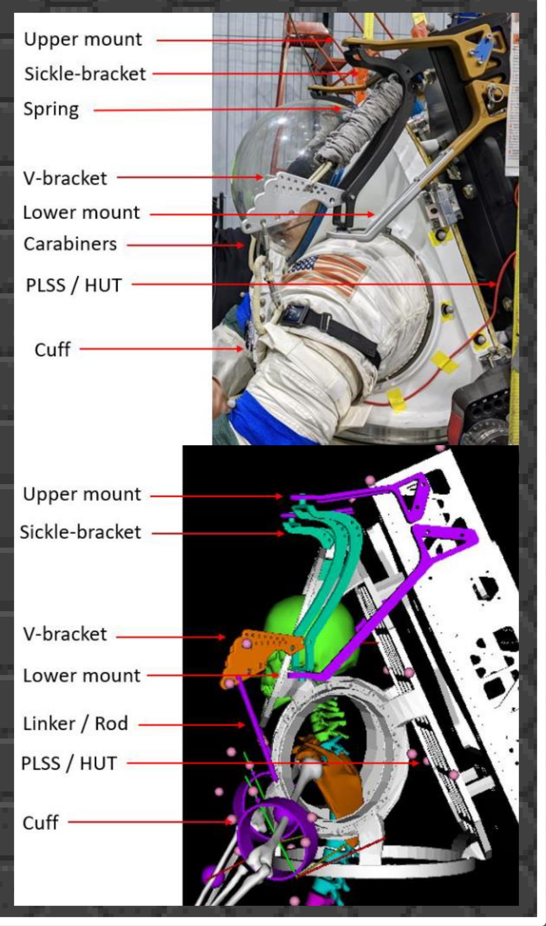
MODELING AND SIMULATION OF THE ANGEL UPPER LIMB OFFLOAD DEVICE: BRANCHING INTO NEW METHODS

L.B. Nilsson[1], D. Frenkel[2], K. H. Lostroscio[3], L. J. Quiocho[3], C. E. Beck[3]
[1]Metecs, Inc., 1030 Hercules Ave., Houston, TX 77058
[2]CACI, Inc., 2100 Space Park Dr., Houston, TX 77058
[3]NASA Johnson Space Center, 2101 E NASA Parkway, Houston, TX 77058

ARGOS Negation of Gravitational Effects on the Limbs (ANGEL)

- Goal: Providing tunable offload to upper limbs
- Tested in the Protype Immersive Technology (PIT) lab and the Active Response Gravity Offload System (ARGOS).
- What about motions from tests without ANGEL? Virtual configurations? Alternative springs, linkers, even cuff?
- Need a way to calculate ANGEL angles based on subject motions alone → Calculate Angles plugin!

Perform motion capture of a subject with or w/o ANGEL → Run Inverse Kinematics (IK) on trajectory of person → Run plugin to find theoretical trajectory of ANGEL / ? / Run IK to find trajectory of ANGEL → Determine offload force, arm angles, and joint torques



Methods

INPUT
Human motion ANGEL configuration

↓

Find cuff rotation by calculating highest point on the cuff in the sickle axis direction (rod attach point)

→

Sickle angle tracks rod attach point

→

V-bracket & linker angle optimized by minimizing spring length*

→

Find testAngles

If (springLength < previous)
previous = springLength
bestAngles = testAngles

Check all tilts for +/- maxTilt

Test new cuff tilt position & find rod attach point for that tilt

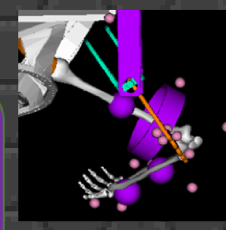
OUTPUT
Spring force vector
Offload force vector
Spherical arm angles
ANGEL angles

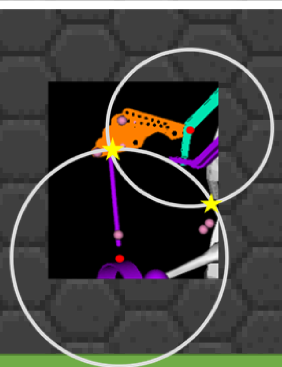
→

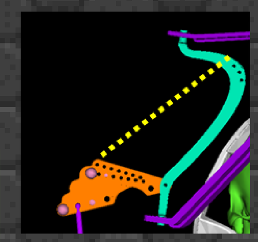
Find joint torques with inverse dynamics

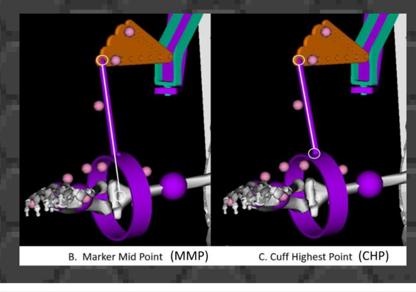
↓

Find joint torques in spherical and rotated frames





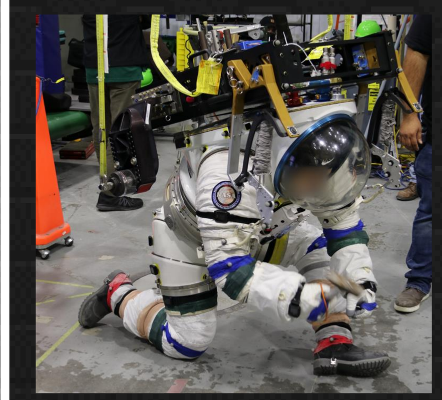


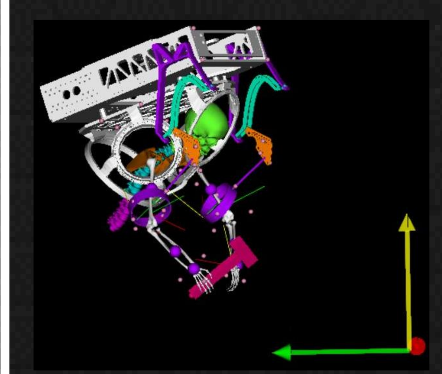


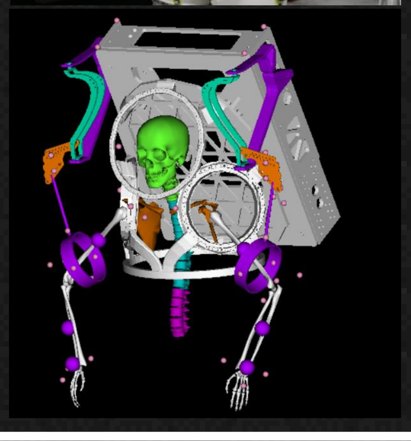
*Intersection of circles indicates acceptable angles where linker, V-bracket, and cuff remain connected. Of the two intersection points satisfying geometric constraints, the one corresponding to a shorter spring length is chosen

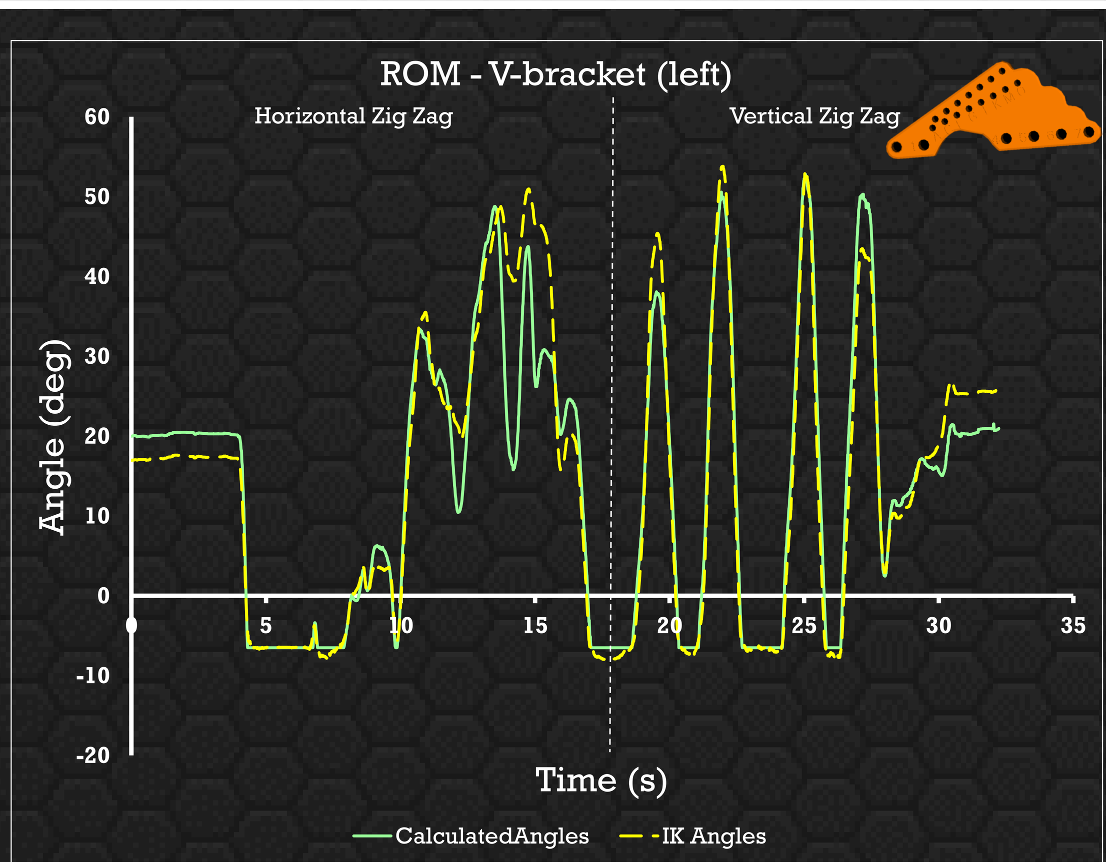
ARGOS Results

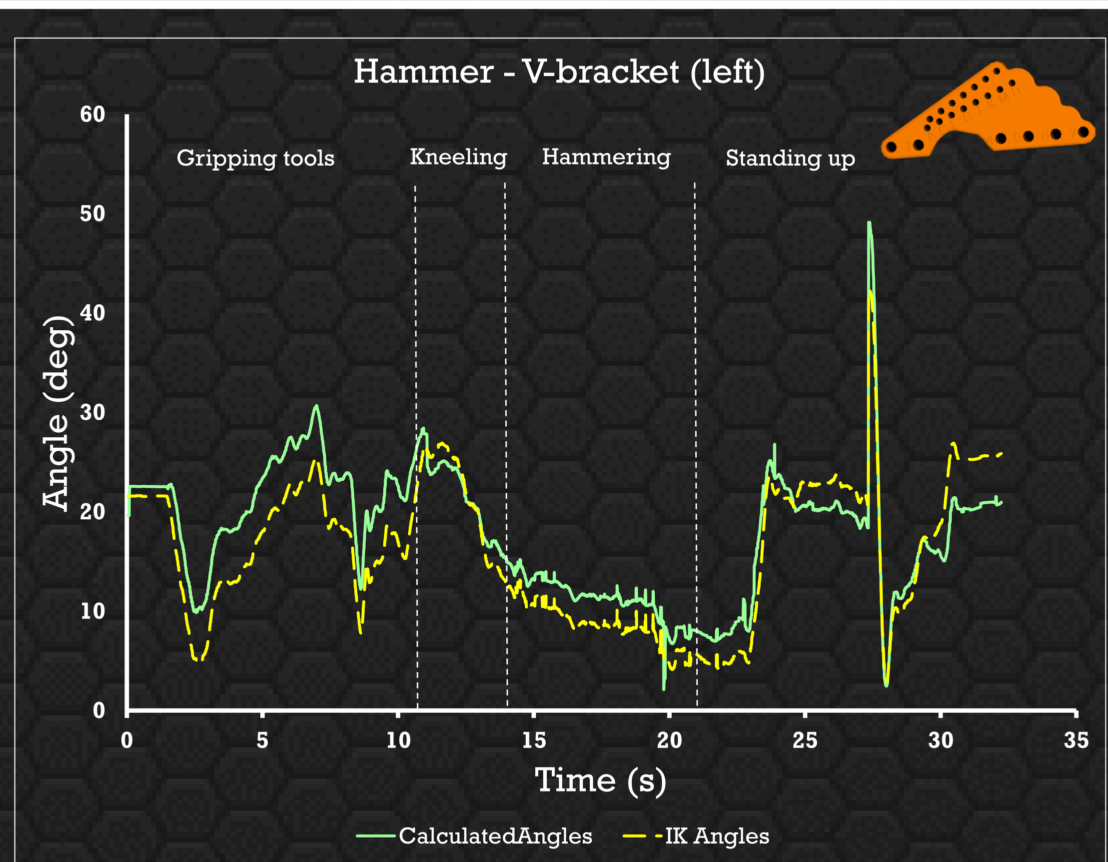
- Two exercises are presented here. A range of motion (ROM) task in which the arms are swept in large zig zags first horizontally and then vertically. Second, a hammering trial.
- We cannot compare linker or cuff angles due to limitations in the data collection – we focus on V-bracket angles and offload forces.
- There is good agreement in results, except for when arm positions are near the edge of the user's range of motion
- Uncertainty in linker angles and difficulty in measuring them experimentally limits the accuracy in the offload force.

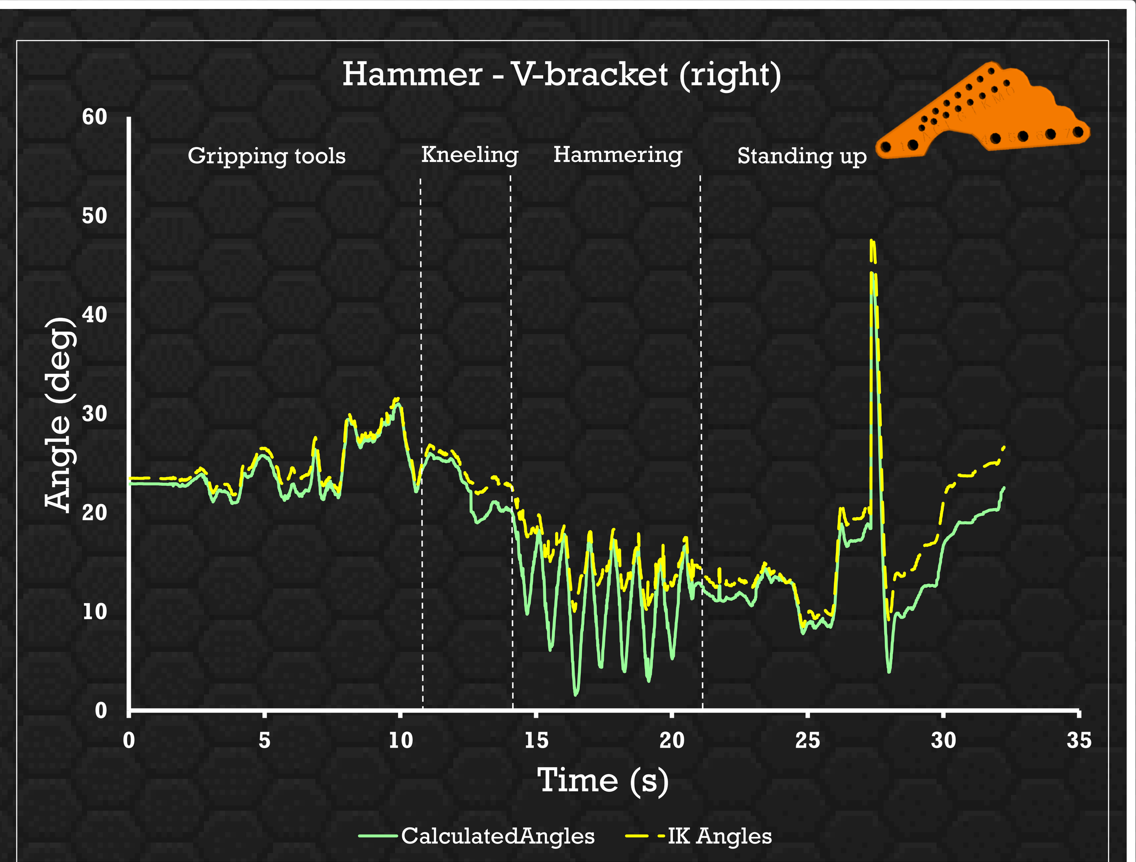


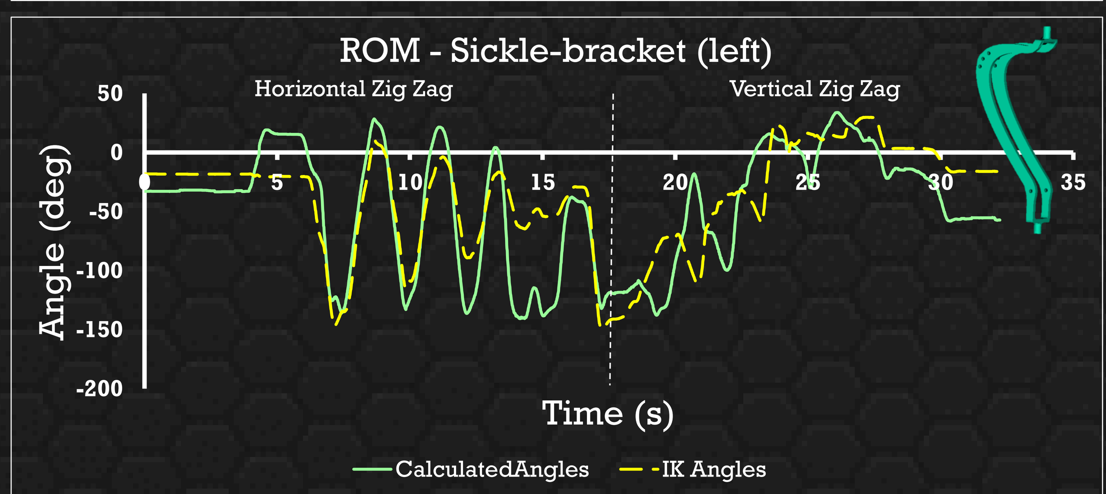


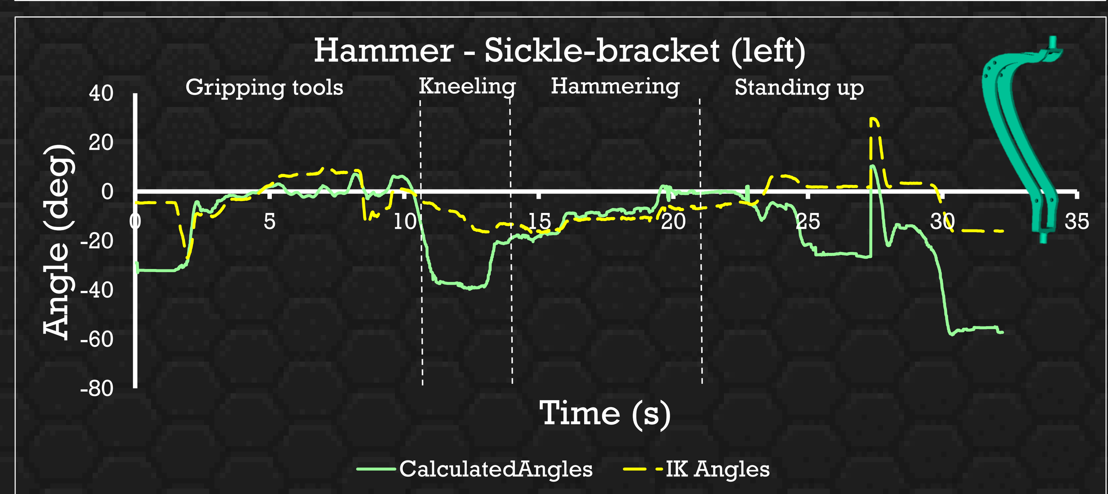


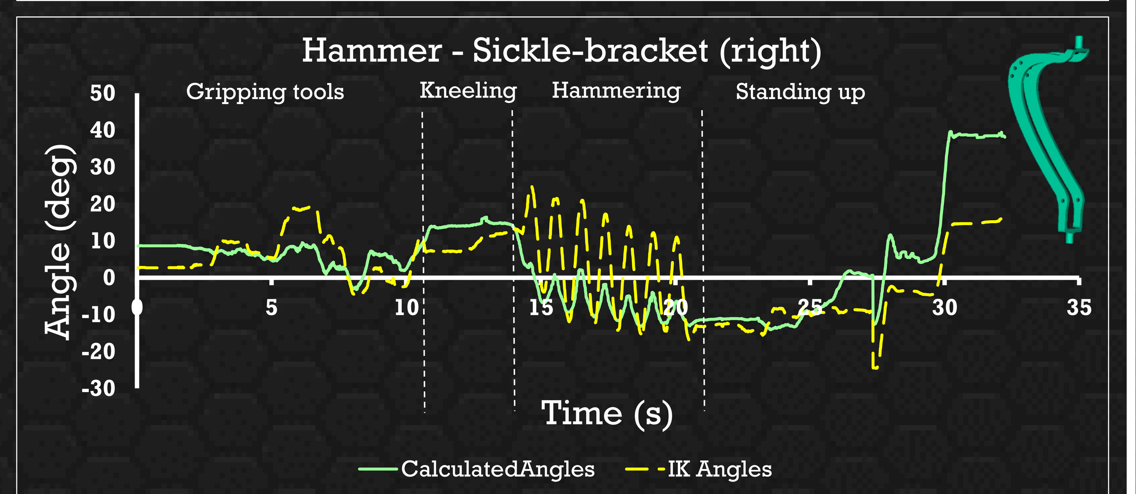


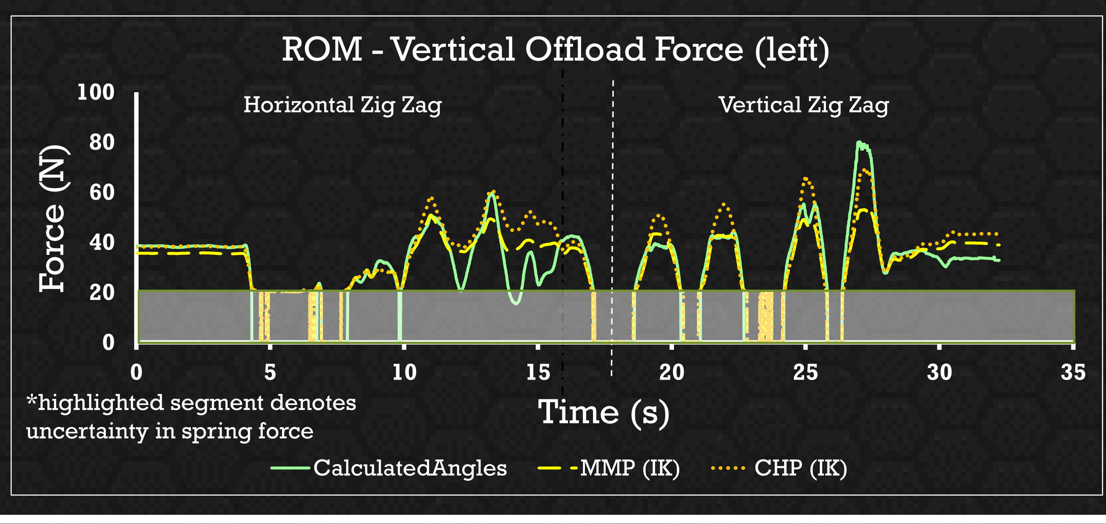




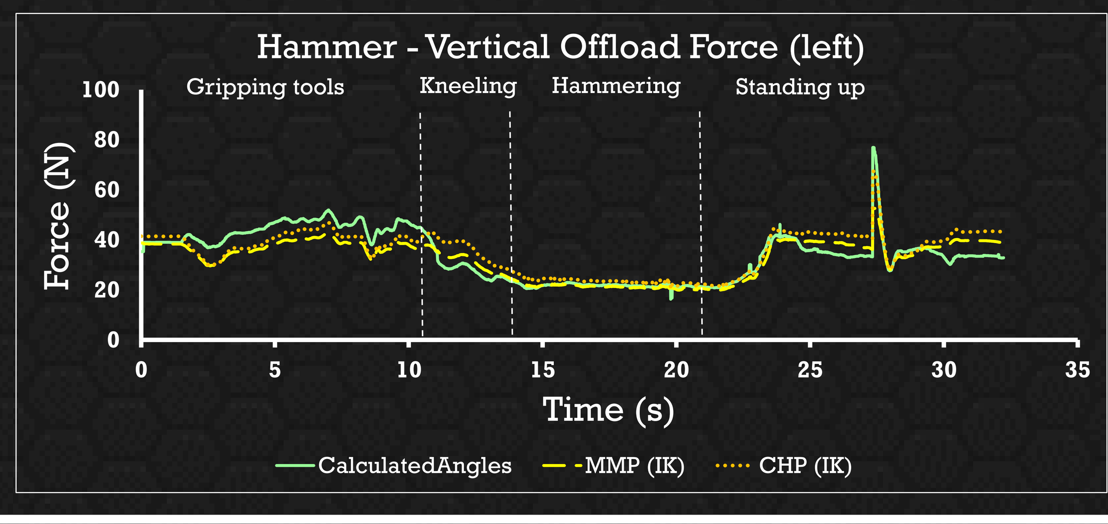


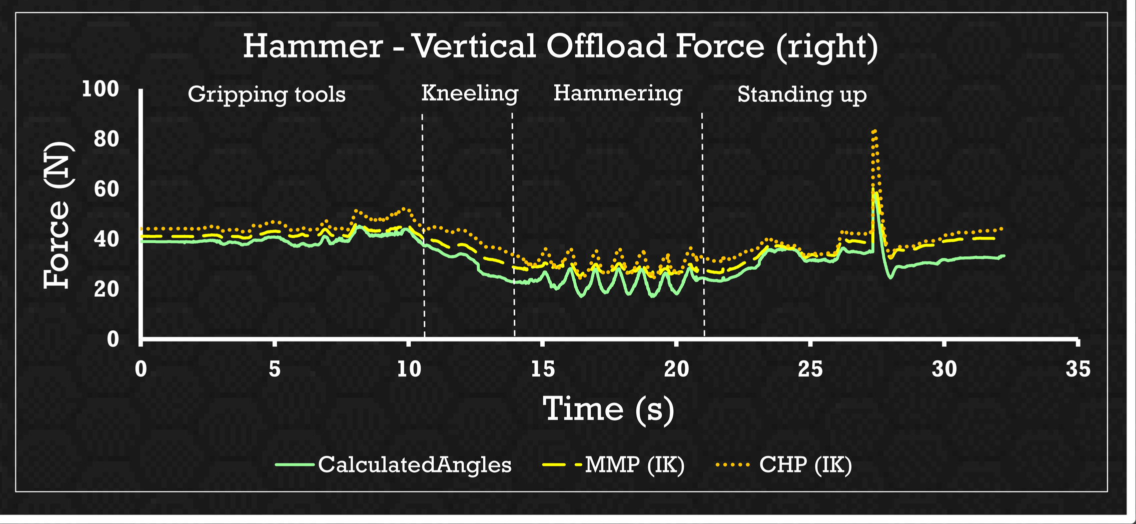






*highlighted segment denotes uncertainty in spring force





Acknowledgements

- Simulations & modeling described here was performed within the Simulation and Graphics Branch (ER7), ANGEL design was performed by the Flight Systems Branch (ER3), and testing was a joint effort.
- This work was completed by the Digital Astronaut Simulation (DAS) team.

References

[1] Delp, S.L.,et. al. OpenSim: Open-source software to create and analyze dynamic simulations of movement. IEEETransactions on Biomedical Engineering, 54(11), pp 1940-1950.(2007)
[2] Nilsson, L., Frenkel, D., Lostroscio, K., "Quantification of ANGEL Offload and Shoulder Torques During PIT Testing", Rev A, Apr. 19, 2022. [METECS-R-186]
[3] Nilsson, L., Frenkel, D., Lostroscio, K., "Quantification of ANGEL Offload and Shoulder Torques During ARGOSTesting", Rev A, Sep. 30, 2022. [METECS-R-190]
[4] Nilsson, L., et al., "Modeling and Simulation Efforts to Support Improved Comfort in ARGOS", NASA HRP IWS 2022

Conclusion & Future Work

- Our current approach has several approximations and needed improvements but is already showing good agreement for some ANGEL components and trials in ARGOS testing. Lack of spring tension and physical disconnection within the ANGEL system are readily detected.
- Higher fidelity modeling of the cuff (tilt, sliding, rotation) could improve agreement in results, but further characterization of the cuff interaction with a spacesuit is needed.
- Adding bracket limits according to contact and mathematical singularity avoidance is in work.
- Accurate linker modeling is a continuing challenge, perpetuated by difficulties in tracking carabiners with motion capture markers.
- Comparing IMU vs IK human motions is future and ongoing work.
- Using forward dynamics to model hysteresis and friction is potential future work.
- Implementing a more rigorous optimization scheme and adding a "saved states" feature for test configurations is potential future work.